National Positioning, Navigation, and Timing Architecture

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An interagency team, sponsored by the Departments of Defense and Transportation and led by the National Security Space Office, has developed a National Positioning, Navigation, and Timing (PNT) Architecture that will substantially affect future government- and commercially-provided PNT products and services. The Architecture envisions sustained U.S. global leadership in PNT through a strategy that makes greater PNT capabilities more generally available. The strategy is supported by vectors, or enterprise architecture elements, for using multiple PNT-related phenomenologies and interchangeable PNT solutions, PNT and Communications synergy, and cooperative organizational structures.

I. Introduction

The Office of the Assistant Secretary of Defense for Networks and Information Integration (OASD/NII) and the Under Secretary of Transportation for Policy (UST/P) sponsored a National Positioning, Navigation, and Timing (PNT) Architecture Study in response to Department of Defense (DoD) and Civil Agency recommendations to develop a comprehensive National PNT Architecture. The Architecture would serve as a framework for developing future PNT capabilities and supporting infrastructure, providing more effective and efficient PNT capabilities focused on the 2025 timeframe and an evolutionary path for government-provided systems and services.

II. Background

The study considered a wide range of architectural elements: the providers of PNT products and services; the users of PNT products and services; the physical domains in which PNT is provided and used; different PNT-enabled applications; and the technical sources and means by which PNT information is created, stored, and disseminated. Figure 1 shows examples of items that were considered during architecture development.

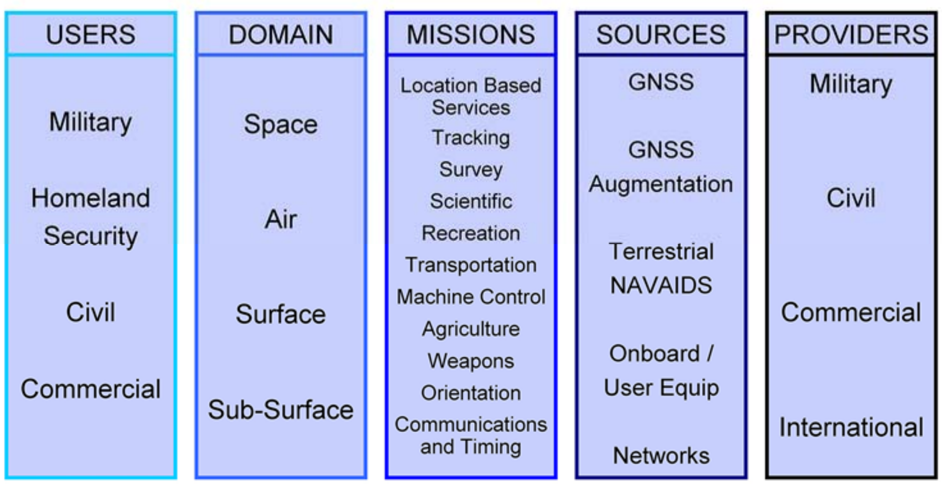

Figure 1: Exemplar PNT Architecture considerations

The study found wide variation in the extent to which different types of users were present in different domains, and the relative number of users performing different missions, as illustrated in Figure 2.

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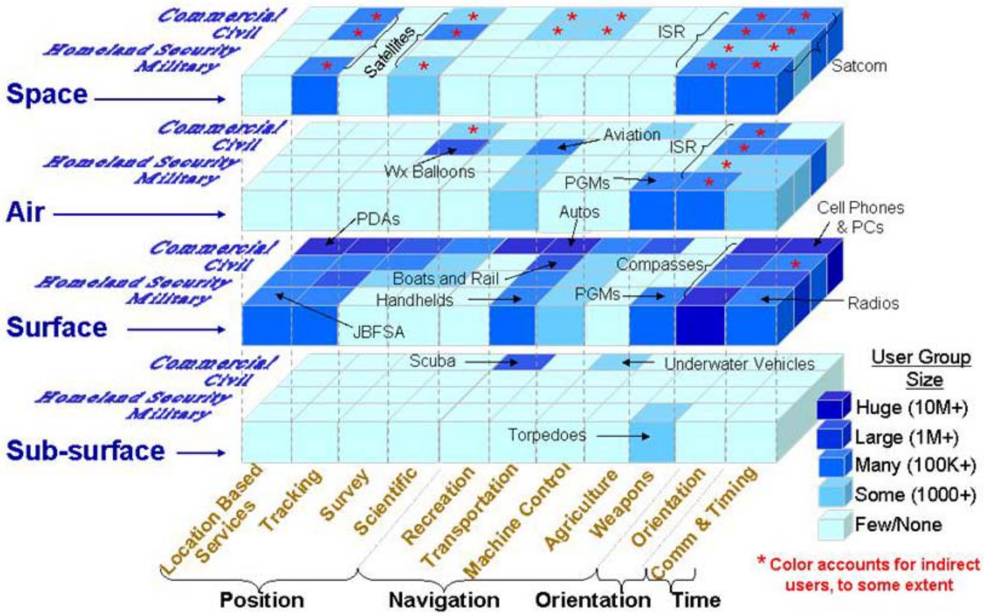

Figure 2: Illustration of the relative number, type, and domains of PNT application users

The study found that current US PNT architecture that supports these users based primarily on the use of radio frequency (RF) aids: the Global Positioning System (GPS), TACAN, VOR/DME, *etc*., which evolved from RF navigation systems, such as Gee and LORAN, first developed during World War II. This evolution has continued a historical pattern of shifting the burden of providing PNT information from individual users onto centrally-provided radionavigation products and services. The burden has shifted so significantly by the early 21st century that radionavigation has widely supplanted traditional solar observations, stellar observations, and map-and-compass orienteering as a means of precision terrestrial navigation while vastly improving PNT accuracy and precision.

The DoD, in coordination with civil agencies, identified a number of potential gaps and shortfalls in future PNT capabilities as summarized in Figure 3; the study found that gaps and shortfalls are due to environmentally-related attenuation or multipath effects coupled with power levels and frequencies of signals used for radionavigation.

Physically Impeded	Urban Canyon	RF Absorption, Multipath
	Canopy	RF Absorption
	Indoors	RF Absorption, Multipath
	Underground	RF Absorption, Multipath
	Underwater	RF Absorption
EMI	Unintentional	Low-Power RF
	Intentional	Low-Power RF
High Accuracy with Integrity		RF Absorption & Multipath; Tolerances
Notification of Harmful & Misleading Information		Reliable Recognition and Notification
High Altitude and Space Positioning and Orientation		References & Sensors
Access to GIS		C^{4}I

RF

Figure 3: Gaps and shortfalls in the current approach to PNT

The reason for the recent emergence of these perceived gaps and shortfalls is that PNT customers are demanding the convenience, accuracy, and precision available through RF-based PNT capabilities in areas where physics constrains GPS and other current PNT signals that are primarily in the ~1-2 GHz range; for example, these frequencies have difficulty penetrating underneath dense foliage and inside buildings as they are readily absorbed by water or reflected by building materials. There are two general types of technologically-based solutions to these problems, each of which has significant implications for the overall architectural approach:

1) Develop autonomous capabilities to increase customer independence from RF-based PNT aids and sources while maintaining the performance and convenience of RF-based capabilities. This approach decreases the dependence of individual users on centralized PNT infrastructure by shifting more of the burden of responsibility for PNT back onto those same users.

2) Make the RF capabilities upon which the architecture depends more robust so that they penetrate areas where current RF-based capabilities are inhibited. This approach continues the overall historical trend of shifting more of the burden of responsibility onto centralized PNT infrastructure in order to reduce the PNT burden on individual users.

The PNT Architecture Development Team (ADT) also considered shortfalls that were not specifically tied to the physics of RF communications, such as access to Geospatial Information Systems (GIS) data, but found these issues could be addressed in the context of specific techniques for the reliable recognition and notification of the presence of misleading or harmful PNT information; improved PNT sensors and reference data for high altitude and space positioning and orientation; and improved Command, Control, Communications, and Intelligence (C4I) capabilities to provide better access to Geospatial Information Systems (GIS). These improvements would need to be part of the fundamental PNT infrastructure regardless of which technical approach, or combination of approaches, was used with regard to increasing or decreasing user burden and reliance on centralized PNT infrastructure.

III. Development

The PNT Architecture Development Team (ADT) identified three architectures, as shown in Figure 4, as it worked through fundamentally different national approaches to PNT: an “As-Is” Architecture describing the current mix of *ad hoc* capabilities; an Evolved Baseline (EBL) anticipating future capabilities based on current planning, programming documents, and expected technology advances; and a “Should-Be” Architecture addressing projected future needs and capability gaps with a long-term enterprise architecture approach. The PNT Architecture identifies the vision, strategy, vectors, and recommendations that lead to the necessary “Should Be” architecture capabilities.

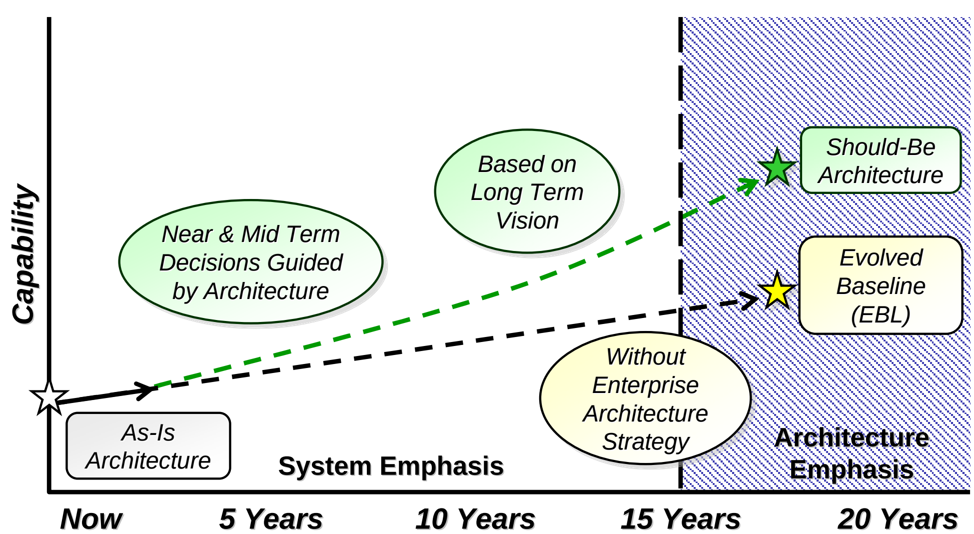

Figure 4: As-Is, EBL, and Should Be Architectures

The National PNT Architecture provides a vision for US leadership in global PNT by promoting a "Greater Common Denominator" strategy, which emphasizes meeting the core needs of many users through externally-provided, commonly-available solutions rather than through individually-customized systems. The architecture also embraces the wide adoption of low-burden (*e.g.*, size, weight, power, and cost) autonomous capabilities to mitigate the dependency of individual users on a largely radio frequency (RF)-based PNT infrastructure. Managing the relationship between common-dependent and autonomous solutions will require continual evaluation of new material and non-material solutions, and balancing the need for a military advantage with the benefits of providing greater common capabilities. The main elements of the PNT Architecture are summarized in Figure 5:

- A vision of United States leadership in global PNT
- A "Greater Common Denominator" strategy, with supporting recommendations, to achieve the vision
- Four architectural vectors, each with a number of supporting recommendations, that together support the complete guiding principles of the National PNT Architecture
  1) Use multiple phenomenologies to the maximum extent practical to ensure robust availability
  2) Strive for interchangeable solutions to enhance efficiency and exploit source diversity
  3) Promote, where appropriate, fusion of PNT with new and evolving communications capabilities
  4) Promote interagency coordination and cooperation to ensure the necessary levels of information sharing

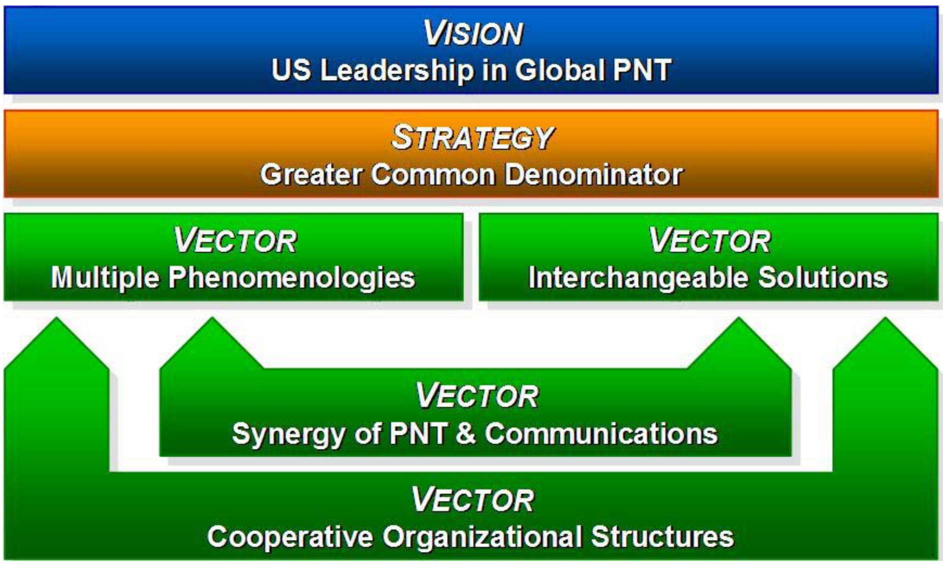

Figure 5: PNT Architecture Vision, Strategy, and Vectors

IV. Architecture Vision

The National PNT Architecture's vision is for the United States to achieve leadership in global PNT by efficiently developing and fielding effective PNT capabilities that are available worldwide, based on the policy foundation set by National Security Presidential Directive, "National Space-Based Positioning, Navigation, and Timing Policy," December 8, 2004.[3] The US can achieve this vision by implementing the following practices:

- Developing and adhering to stable policies, building credibility both domestically and internationally, thus enabling the commercial sector to innovate and advance PNT through competitive practices
- Providing PNT capabilities in a coordinated manner, sharing information, and presenting a unified view of National objectives by promoting inter-agency cooperation across the full scope of PNT activities
- Maximizing the practical use of military, civil, commercial and foreign systems and technologies, and leading the effort to integrate all available signals to achieve assured, higher-performing PNT solutions
- Judiciously developing and applying comprehensive standards and best practices, while encouraging others to adopt or align with US capabilities.

[3] Document is not available for public dissemination. Copies of a fact sheet are available at http://pnt.gov/policy/

V. “Greater Common Denominator” Strategy

The National PNT Architecture seeks to fulfill the architectural vision by promoting a “Greater Common Denominator” strategy to effectively provide standard solutions that meet the majority of users’ needs. In this strategy, users are predominantly dependent upon external sources of PNT information where “greater” commonly available capabilities meet a larger proportion of the population’s needs. Specialized solutions will continue to exist where it is either inefficient or inappropriate to make the required capability more commonly available, to ensure robustness for certain applications, or to meet agency regulatory responsibilities. This strategy also encourages the wide adoption of low-burden autonomous capabilities to mitigate dependency on the PNT infrastructure. Finally, the US must continue to balance the need for a national security advantage as greater capabilities become more commonly available. There are five architecture recommendations that specifically support the implementation of this strategy:

1. Maintain GPS as a cornerstone of the National PNT Architecture

GPS modernization will provide greater capability on a global scale, where the number of users is limited only by ready availability and access to GPS receivers. Additional frequencies and spectral separation, more robust signal structures, real-time networking, and anti-jam enhancements will result in greater capabilities that will be more commonly available.

2. Monitor PNT signals to verify service levels, observe environmental effects, detect anomalies, and identify signal interference for near real-time dissemination

The U.S. government PNT infrastructure must bear the burden of monitoring the PNT-related signals it intends to use, to include defining and refining relevant benchmarks. This will allow the U.S. to become a trusted source for data measuring the absolute and comparative performance of PNT systems; to detect environmental effects, anomalies, and interference with US systems; and to prepare the US for use of foreign PNT services. An assessment of the specific monitoring capabilities will include military and civil assessments of foreign and domestic government signals and services.

3. As GPS modernization or other methods demonstrate new operational capabilities, agencies should transition or divest US GNSS augmentation assets that are unnecessarily redundant to their requirements

Significant investments in US Global Navigation Satellite System (GNSS) modernization may result in an opportunity to divest or transition US GNSS augmentation assets that become unnecessarily redundant. For example, the availability of multiple GPS frequencies for public use will allow the public to receive the benefits of local, real-time corrections for ionospheric delay. This creates a potential to optimize the deployment of reference stations and processing facilities which would be needed for PNT signal monitoring.

4. Continue to investigate methods to provide high-accuracy-with-integrity solutions for safety-of-life applications

Providing High Accuracy with Integrity for Safety-of-Life applications is a stressing future gap for the PNT Architecture. The US should establish the level of integrity required by applications that need position accuracy on the order of a few decimeters, identify the level of capability of current solutions, and investigate the necessary infrastructure changes and reference frame updates to support a future accuracy of 10 centimeters with integrity. Research is also needed for improved and alternative methods for absolute and relative navigation techniques, and to identify methods to ensure seamless integration of multi-source PNT information.

5. Develop a national approach to protect military PNT advantage

The nation must protect its military PNT advantage in light of the Greater Common Denominator strategy. The availability of multi-phenomenology technologies to potential adversaries increases the complexity of PNT denial. Military advantage may likely go to those who equip fastest and have doctrine and training to efficiently exploit those capabilities. Therefore, the US should review PNT capability export controls for autonomous systems and integration technologies given the proposed diverse sources and paths approach.

VI. Multiple Phenomenologies Vector

The National PNT Architecture promotes the use of multiple phenomenologies to ensure robust availability and address gaps in the ability to operate in physically and electromagnetically impeded environments. “Multiple phenomenologies” refers to diverse phenomena such as radio frequencies and inertial sensors, and to employing diverse sources and data paths that use those physical phenomena (*e.g.*, multiple radio frequencies and services). There are four recommendations regarding the implementation of this vector; numbering continues from the prior section:

6. Encourage appropriate development and employment of equipment that integrates information from diverse sources and information paths

User equipment should integrate diverse sources and information paths, since these can provide more robust solutions than their single phenomenology counterparts, as diagramed in Figure 6. For example, inertial and autonomous timekeeping systems can allow for coasting through outages in service outages of RF-based PNT provider services, and aid in reacquiring those RF signals. RF-aided PNT could communicate high-quality PNT capabilities and information by leveraging the physical attributes and capabilities of RF spectra not currently reserved for navigation. These types of approaches could bring the benefits of RF-aided PNT to locations and operating conditions where they are not now available.

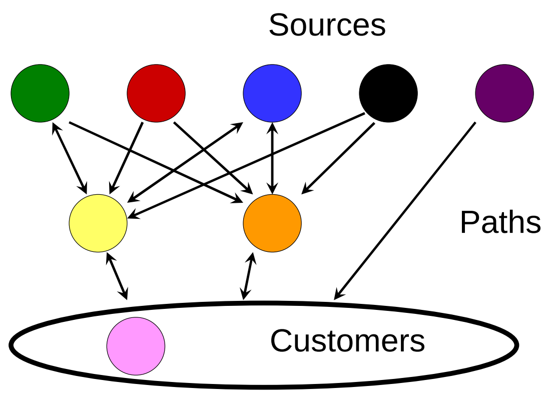

Figure 6: Diverse sources and information paths

7. Assess the potential for the use of foreign PNT systems for safety-of-life applications and critical infrastructure users and, as appropriate, develop clear standards and criteria for their use

The Architecture acknowledges that developers and customers will utilize all systems that offer added value, and therefore anticipates widespread availability of combined, multi-system PNT receivers in a global and increasingly competitive commercial marketplace. While US solutions should be promoted as a first choice, the nation should plan to remove US obstacles to use of compatible foreign PNT systems. Therefore, the US should assess the use of foreign PNT systems with respect to enhancing solution accuracy and availability, and to provide robustness in the event of system outages or vulnerabilities. The US should also work through standards organizations to identify clear criteria for usage of and service compatibility with foreign systems.

8. Continue military PNT exclusive use policy while studying development of capabilities to enable military use of other signals

The US should maintain policies that ensure military forces are not critically dependent upon foreign systems while maintaining and developing capabilities to deny the hostile use of PNT. The use of foreign PNT systems and signals of opportunity may increase PNT solution accuracy and availability, and provide a contingency capability. The U.S. should therefore initiate a thorough study regarding conditions to enable DoD use of US civil and foreign PNT sources, to include considering impacts and costs to user equipment, signal monitoring and alert capabilities, and robust integrity and information assurance algorithms.

9. Promote standards for PNT pseudolites and beacons to facilitate interchangeability and avoid interference

“Pseudolites,” which are “pseudo-GPS satellites” that provide ranging signals from surveyed terrestrial locations, and RF beacons can support location-based PNT services where GNSS signals are impeded. Widespread use of these devices has the potential to create compatibility, interoperability, and spectrum noise challenges, so standards should be promoted to facilitate the integration and deconfliction of pseudolites and beacon with other RF-based PNT solutions. Furthermore, user communities should explore the appropriate balance between pseudolites, beacons, and autonomous technologies.

10. Study evolution of space-based and terrestrial PNT capabilities to support diversity in PNT sources and information paths

Current plans for future systems should be revisited in light of the multiple phenomenology vectors. For example, space-based PNT is and will remain a cornerstone of the PNT architecture, but the Architecture should envision adding to the current GPS construct as technology evolves, as some terrestrial PNT systems have limited utility for some transportation modes or do not fit with perceived needs for 2025. Subsequent review and revision of PNT systems will be needed as the current vectors and recommendations begin to improve US PNT capabilities.

11. Ensure critical infrastructure precise time and time interval users have access to and take advantage of multiple available sources

The US should ensure critical infrastructure Precise Time and Time Interval (PTTI) users have access to and can take advantage of multiple sources of PTTI information. Near-term policy options should be explored to encourage robust solutions while identifying future PTTI requirements for critical infrastructure elements and fostering continued development of PTTI solutions.

VII. Interchangeable Solutions Vector

The National PNT Architecture promotes the interchangeability of solutions to enhance efficiency and exploit source diversity. Interchangeable solutions have a degree of compatibility and interoperability that allows the combination of diverse sources to obtain a superior PNT solution. There are four recommendations regarding the implementation of this vector, with numbering continued from the prior section:

12. Use participation in international PNT-related activities to promote the interchangeability of PNT sources while assuring compatibility

The US should refine PNT-related policy goals and objectives to include interchangeability of PNT data sources and compatibility between PNT service providers, with the goal of widening markets for US PNT products in the global marketplace. These efforts should leverage US involvement and leadership in international fora.

13. Evolve standards, calibration techniques, and reference frames to support future accuracy and integrity needs

Substantial improvement in PNT capabilities will require fundamental improvements in the information infrastructure underlying those capabilities, so the US should determine the accuracy of standards, calibration techniques, and reference frames needed to support projected real-time absolute positioning accuracy and integrity needs. Interface, performance, information exchange, and other standards will be needed for PNT sensors to be interchangeable from the PNT user perspective. Calibration capabilities and reference frames must be an order of magnitude better than required measurement accuracy, and measurement accuracy needs will likely be more demanding than they are today. Areas for exploration include earth-fixed and celestial reference frames, earth orientation, grids, timing, frequency, physical models, and data transfer techniques.

14. Identify and develop common standards that meet users' needs for PNT information exchange, assurance and protection

Using information from multiple and diverse phenomenologies will likely produce chaotic, non-assured, and insecure data without standardized information interfaces. Users need convenient access to multiple data sources via diverse paths and all relevant PNT-related information to make informed decisions while that information must be protected against unauthorized use, abuse, and exploitation. The US should therefore review whether current frameworks are sufficient in these areas or develop relevant appropriate standards.

15. Establish common standards that meet users' needs for the depiction of position information for local and regional operations

Using different coordinate system grids to define locations can impact interoperability and compromise safety, since errors can be introduced when converting between the different coordinate systems that exist within and between civil and military communities. The US should reemphasize directives to use Military Grid Reference Systems (MGRS) and the civil equivalent, US National Grid (USNG); enforce existing National Spatial Data Infrastructure guidance on use of USNG; and review and amend military tactics, techniques, and procedures, as appropriate, to require use of MGRS (or USNG as documented) to ensure interoperability when grid coordinates are needed for local or regional tactical ground operations.

VIII. Synergy of PNT and Communications Vector

The National PNT Architecture leverages users' increasing connectivity to communications networks for use as sources of PNT, not merely as data channels for PNT aiding and augmentation data. This Vector promotes the fusion of PNT features with new and evolving communications capabilities, resulting in increased robustness by offering services outside of traditional radionavigation spectrum. This vector has one recommendation:

16. Identify and evaluate methods, standards and potential capabilities for fusion of PNT with communications

Data communications networks currently support PNT capabilities by carrying PNT aiding and augmentation data, GIS data, *etc*.; however, opportunities exist to exploit the synergy between RF-based PNT and communications by leveraging communications capabilities to provide PNT capabilities directly. This is consistent with the multi-phenomenology vector of employing diverse sources and information paths, and would increase PNT robustness by offering services outside of traditional radionavigation spectrum. Leadership and initiative are needed to avoid stove-piped solutions, and detailed assessments are needed regarding specific solutions, so the US should establish a community of experts to pursue synergies between communications and PNT. Initially, the US should study existing PNT/Communications fusion efforts, such as cellular and WiFi networks, "iGPS," military tactical radio networks, E911, the Air Force Satellite Control Network, and NASA's Space Communications Architecture to help determine what provides the best options for both systems and their users, and examine the potential for integrating PNT capabilities into new or updated communications capabilities.

IX. Cooperative Organizational Structures Vector

The National PNT Architecture will require extensive interagency coordination and cooperation to ensure necessary levels of information sharing across the PNT Enterprise. This vector includes the establishment of coordination processes to ensure effective operations, efficient acquisition (for both data source equipment and user equipment), and relevant science and technology application development. This vector also incorporates an enterprise-level PNT modeling and simulation capability to benefit, for example, mission planning, user equipage decisions, and subsequent architecture efforts. There are three recommendations regarding the implementation of this vector:

17. Develop a national PNT coordination process

National PNT needs, synergies, and decisions on the national architecture would benefit from a long-term, national PNT coordination process extending beyond space-based PNT. The US should identify and organize the nation's expertise to develop a National PNT Coordination Process. The process could address PNT needs analysis, program assessments, and cost estimation; advise and encourage government science and technology investments, as well as commercial research and development, in key PNT-related technologies; and perhaps provide system engineering and integration support to PNT program offices, service providers, and customers.

18. Identify and leverage centers of excellence for PNT phenomenology and applications

The National PNT Coordination Process could focus the national effort on science and technology, ensuring sufficient breadth and depth with efficient use of national resources. For example, the process could offer knowledge resources to user equipment developers regarding the performance and cost of alternative technologies.

19. Define, develop, sustain, and manage a PNT modeling and simulation core analytical framework

The US lacks an enterprise-level PNT modeling and simulation capability. The existing capability gap will only grow with an enterprise evolving toward the use of multiple phenomenologies and interchangeable sources. Future enterprise-level architecture and user equipage decisions will benefit from analytical support. Under the auspices of the National PNT Coordination Process, the US should develop a core analytical framework and initial capability to be made available to the community.

X. Conclusion

The National PNT Architecture has been approved by its co-sponsoring organizations, and the U.S. Government is currently developing a plan to transition from the "As-Is" to the "Should Be" architecture by the 2025 timeframe. This plan will require a structured approach for the implementation and identification of responsible agency participants, and tie programs and plans to each recommendation. This planning process is targeted to support the FY11 budget build process.

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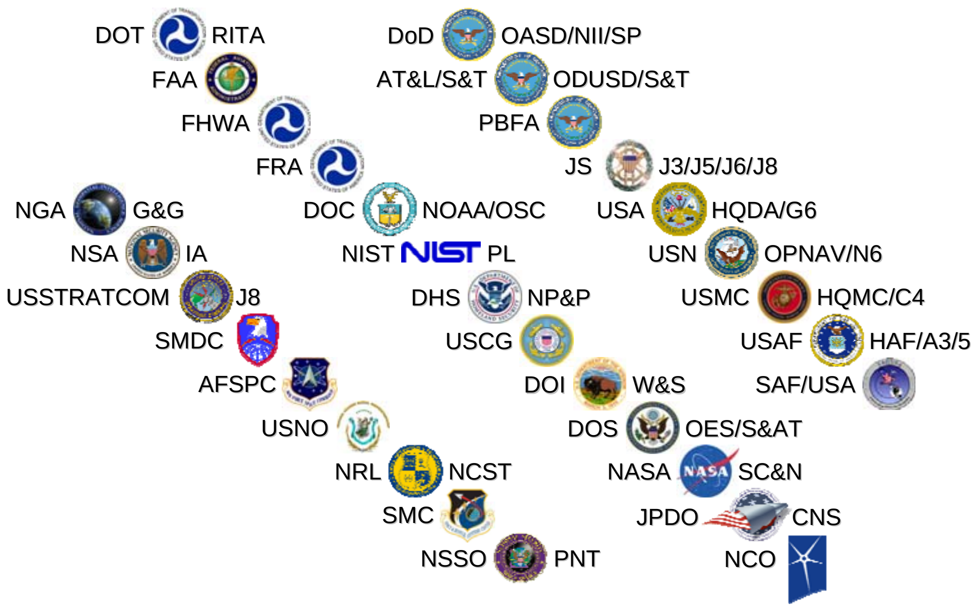

Figure 7: Government contributors to the PNT Architecture effort

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